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U.S. ENVIRONMENTAL PROTECTION AGENCY
NATIONAL EUTROPHICATION SURVEY

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16. ABSTRACT

Annual total phosphorus and total nitrogen loadings to the lake were estimated and subdivided according to either point or non-point source origin. An assessment of the lake's trophic condition and limiting nutrient is also provided. All data collected by the U.S.E.P.A. National Eutrophication Survey during the one year study of the lake and its tributaries are included in the report.

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REPORT
ON
SAND LAKE
BROWN COUNTY
SOUTH DAKOTA
EPA REGION VIII
WORKING PAPER No. 623

WITH THE COOPERATION OF THE
SOUTH DAKOTA DEPARTMENT OF ENVIRONMENTAL PROTECTION
AND THE
SOUTH DAKOTA NATIONAL GUARD

DECEMBER, 1976

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FOREWORD

The National Eutrophication Survey was initiated in 1972 in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to freshwater lakes and reservoirs.

OBJECTIVES

The Survey was designed to develop, in conjunction with state environmental agencies, information on nutrient sources, concentrations, and impact on selected freshwater lakes as a basis for formulating comprehensive and coordinated national, regional, and state management practices relating to point-source discharge reduction and non-point source pollution abatement in lake watersheds.

ANALYTIC APPROACH

The mathematical and statistical procedures selected for the Survey's eutrophication analysis are based on related concepts that:

a. A generalized representation or model relating sources, concentrations, and impacts can be constructed.

b. By applying measurements of relevant parameters associated with lake degradation, the generalized model can be transformed into an operational representation of a lake, its drainage basin, and related nutrients.

c. With such a transformation, an assessment of the potential for eutrophication control can be made.

LAKE ANALYSIS

In this report, the first stage of evaluation of lake and watershed data collected from the study lake and its drainage basin is documented. The report is formatted to provide state environmental agencies with specific information for basin planning [§303(e)], water quality criteria/standards review [§303(c)], clean lakes [§314(a,b)], and water quality monitoring [§106 and §305(b)] activities mandated by the Federal Water Pollution Control Act Amendments of 1972.

Beyond the single lake analysis, broader based correlations between nutrient concentrations (and loading) and trophic condition are being made to advance the rationale and data base for refinement of nutrient water quality criteria for the Nation's freshwater lakes. Likewise, multivariate evaluations for the relationships between land use, nutrient export, and trophic condition, by lake class or use, are being developed to assist in the formulation of planning guidelines and policies by EPA and to augment plans implementation by the states.

ACKNOWLEDGMENT

The staff of the National Eutrophication Survey (Office of Research & Development, U. S. Environmental Protection Agency) expresses sincere appreciation to the South Dakota Departments of Environmental Protection and Game, Fish and Parks for professional involvement, to the South Dakota National Guard for conducting the tributary sampling phase of the Survey, and to those wastewater treatment plant operators who voluntarily provided effluent samples.

Allyn Lockner, Secretary, and Blaine Barker and Duane Murphy, Department of Environmental Quality; Douglas Hansen, Department of Game, Fish and Parks; and James Hayden, Director, State Lakes Preservation Committee provided invaluable lake documentation and counsel during the Survey, reviewed the preliminary reports, and provided critiques most useful in the preparation of this Working Paper series.

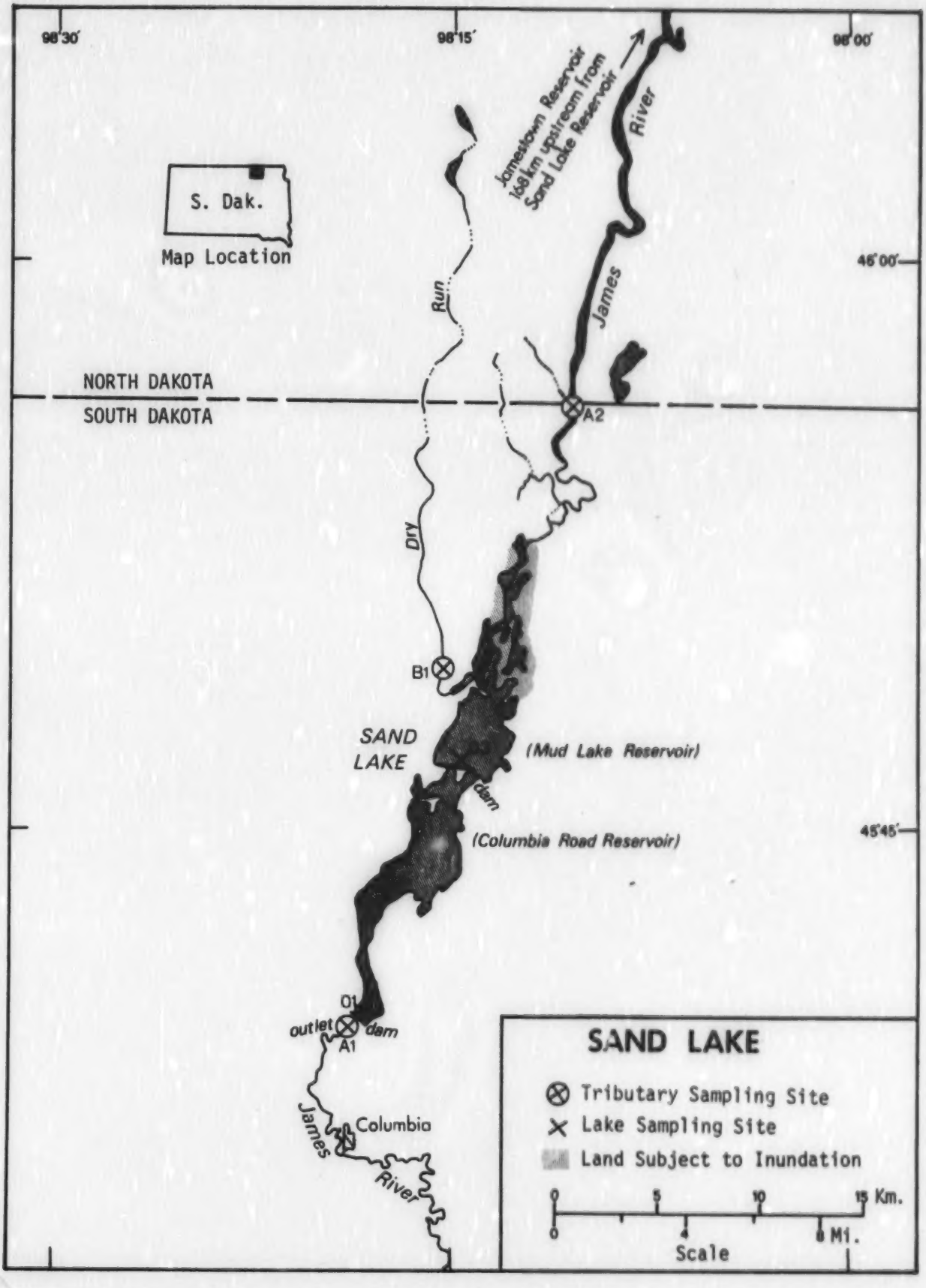
Major General Duane L. Corning, the Adjutant General of South Dakota, and Project Officer Colonel Robert D. Chalberg, who directed the volunteer efforts of the South Dakota National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

NATIONAL EUTROPHICATION SURVEY

STUDY LAKES

STATE OF SOUTH DAKOTA

LAKE NAME	COUNTY
Albert	Kingsbury
Alvin	Lincoln
Angostura	Fall River
Brant	Lake
Byron	Beadle
Clear	Marshall
Clear	Minnehaha
Cochrane	Deuel
Cottonwood	Spink
Deerfield	Pennington
Enemy Swim	Day
Herman	Lake
John	Hamlin
Kampeska	Codington
Madison	Lake
Mitchell	Davidson
Norden	Hamlin
East Oakwood	Brookings
West Oakwood	Brookings
Pactola	Pennington
Pickerel	Day
Poinsett	Brookings, Lake
Red Iron South	Marshall
Richmond	Brown
Roy	Marshall
Sand	Brown
Sheridan	Pennington
Stockdale	Custer
East Vermillion	McCook
Wall	Minnehaha
Waubay	Day


98°30'
98°15'
98°00'
46°00'
45°45'
Jamestown Reservoir
168 km upstream from
Sand Lake Reservoir
James River
S. Dak.
Map Location
Dry Run
NORTH DAKOTA
SOUTH DAKOTA
A2
B1
SAND LAKE
(Mud Lake Reservoir)
dam
(Columbia Road Reservoir)
O1
outlet
dam
A1
James River
Columbia
SAND LAKE
Tributary Sampling Site
Lake Sampling Site
Land Subject to Inundation
0 5 10 15 Km.
0 4 8 Mi.
Scale

SAND LAKE

STORET NO. 4626

I. CONCLUSIONS

A. Trophic Condition:

Survey data indicate that Sand Lake, a National Wildlife Refuge, is eutrophic. It ranked twenty-eighth in overall trophic quality when the 31 South Dakota lakes sampled in 1974 were compared using a combination of six water quality parameters*. Twenty-eight of the lakes had less median total phosphorus and median dissolved orthophosphorus, 12 had less and one had the same median inorganic nitrogen, 21 had less mean chlorophyll a, and 20 had greater mean Secchi disc transparency.

Survey limnologists reported heavy growths of emergent and submergent macrophytes and dense algal blooms during their sampling visits.

B. Rate-Limiting Nutrient:

The algal assay results indicate that Sand Lake was nitrogen limited at the time the sample was collected (09/18/74). The lake data indicate nitrogen limitation at all sampling times.

C. Nutrient Controllability:

1. Point sources--The listed point sources accounted for 14.0% of the total phosphorus load to Sand Lake during the sampling year. LaMoure and Oakes, North Dakota, contributed an estimated 4.7%

* See Appendix A.

and 9.3% of the total, respectively. Jamestown, North Dakota, located well upstream on the James River, may affect Sand Lake; however, the nutrient export rates of the river at sampling station A-2 (see map, page v) indicate little impact (see below).

The present phosphorus loading of 7.07 $g/m^2/yr$ is over seven times that proposed by Vollenweider (Vollenweider and Dillon, 1974) as a eutrophic loading (see page 15). However, Vollenweider's model may not be applicable because the mean hydraulic retention time of Sand Lake is a very short 12 days. Nonetheless, the existing trophic condition of Sand Lake is evidence of excessive nutrient loads.

It is not likely that point-source phosphorus control would result in any significant improvement in the trophic condition of Sand Lake unless non-point phosphorus contributions to the James River can also be reduced. Note that the phosphorus export of the river at station A-2 (15,725 kg) alone provided a loading over five times the eutrophic loading.

2. Non-point sources--Tributaries and immediate drainage contributed an estimated 76.0% of the total phosphorus load during the sampling year. The James River contributed 71.8%, Dry Run contributed an estimated 1.2%, and the ungaged minor tributaries and immediate drainage accounted for an estimated 3.0%.

The nutrient export rates of the James River (page 14) were very similar to those measured at the inlet to Jamestown Reservoir (2 kg P and 23 kg N/km^2/yr) upstream from the City of Jamestown. The similar export rates indicate the Jamestown waste treatment facility had little if any effect on Sand Lake during the sampling year.

Sand Lake is a major Central Flyway migratory waterfowl refuge, and is primarily utilized by snow and blue geese and ducks. On the basis of waterfowl-use information provided by the Refuge Manager (Bair, 1976), the amounts of nutrients contributed to Sand Lake by migratory waterfowl were estimated (see page 10 for method of calculation).

Collectively, the ducks and geese using the Refuge contributed an estimated 9.8% of the total phosphorus load and 3.9% of the total nitrogen load. These estimates may be somewhat high, however, since the mean phosphorus and nitrogen concentrations at the outlet were only 7% and 10% higher, respectively, than at the inlet (see page 14), and part of the difference is attributable to other non-point sources (Dry Run, immediate drainage, and precipitation). In any case, as noted above, the non-point exports of the James River provide far more nutrients than are needed to maintain the eutrophic condition of Sand Lake regardless of waterfowl use.

II. LAKE AND DRAINAGE BASIN CHARACTERISTICS†

A. Lake Morphometry††:

1. Surface area: 3.10 kilometers^2.
2. Mean depth: 0.8 meters.
3. Maximum depth: 1.8 meters.
4. Volume: 2.480×10^6 m^3.
5. Mean hydraulic retention time: 12 days.

B. Tributary and Outlet:
(See Appendix C for flow data)

1. Tributaries -

Name	Drainage area (km^2)*	Mean flow (m^3/sec)*
James River	9,842.0	2.350
Dry Run	129.5	0.007
Minor tributaries & immediate drainage -	333.6	0.007
Totals	10,305.1	2.364**

2. Outlet -

James River	10,308.2**	2.364**

C. Precipitation***:

1. Year of sampling: 27.5 centimeters.
2. Mean annual: 48.5 centimeters.

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† Table of metric conversions--Appendix B.
†† Murphey, 1974.
* For limits of accuracy, see Working Paper No. 175, "...Survey Methods, 1973-1976".
** Includes area of lake; outflow adjusted to equal sum of inflows.
*** See Working Paper No. 175.

III. LAKE WATER QUALITY SUMMARY

Sand Lake was sampled three times during the open-water season of 1974 by means of a pontoon-equipped Huey helicopter. Each time, samples for physical and chemical parameters were collected from one or more depths at three stations on the lake (see map, page v). During each visit, a single depth-integrated (near bottom to surface) sample was composited from the stations for phytoplankton identification and enumeration; and during the last visit, a single 18.9-liter depth-integrated sample was composited for algal assays. Also each time, a depth-integrated sample was collected from each of the stations for chlorophyll a analysis. The maximum depths sampled were near-surface only at stations 1 and 3 and 0.6 meters at station 2.

The sampling results are presented in full in Appendix D and are summarized in the following table.

A. SUMMARY OF PHYSICAL AND CHEMICAL CHARACTERISTICS FOR SAND LAKE
STORET CODE 4626

PARAMETER	1ST SAMPLING (4/26/74) 3 SITES RANGE	MEAN	MEDIAN	2ND SAMPLING (7/10/74) 3 SITES RANGE	MEAN	MEDIAN	3RD SAMPLING (9/18/74) 3 SITES RANGE	MEAN	MEDIAN
TEMP (C)	13.0 - 16.0	15.0	16.0	25.1 - 27.6	26.5	27.3	15.8 - 16.8	16.3	16.4
DISS OXY (MG/L)	9.2 - 10.0	9.5	9.4	2.2 - 15.8	8.6	7.2	8.2 - 10.2	9.1	8.9
CNDCTVY (MCROMO)	496. - 870.	728.	817.	817. - 980.	938.	957.	698. - 849.	771.	776.
PH (STAND UNITS)	8.3 - 8.5	8.4	8.5	8.3 - 9.6	8.9	8.9	7.8 - 8.5	8.3	8.5
TOT ALK (MG/L)	162. - 366.	297.	364.	280. - 314.	298.	298.	445. - 630.	522.	490.
TOT P (MG/L)	0.142 - 0.311	0.203	0.157	0.489 - 0.576	0.536	0.544	0.304 - 0.640	0.417	0.306
ORTHO P (MG/L)	0.018 - 0.034	0.028	0.031	0.307 - 0.445	0.382	0.414	0.056 - 0.288	0.151	0.109
NO2+NO3 (MG/L)	0.040 - 0.060	0.053	0.060	0.050 - 0.090	0.068	0.070	0.020 - 0.030	0.023	0.020
AMMONIA (MG/L)	0.050 - 0.050	0.050	0.050	0.080 - 0.120	0.104	0.100	0.040 - 0.060	0.050	0.050
KJEL N (MG/L)	1.700 - 1.800	1.733	1.700	1.700 - 4.400	2.780	2.200	2.700 - 3.300	3.067	3.200
INORG N (MG/L)	0.090 - 0.110	0.103	0.110	0.130 - 0.210	0.172	0.170	0.060 - 0.090	0.073	0.070
TOTAL N (MG/L)	1.740 - 1.860	1.787	1.760	1.770 - 4.450	2.848	2.290	2.720 - 3.320	3.090	3.230
CHLRPYL A (UG/L)	14.1 - 50.7	29.8	24.6	19.8 - 224.6	75.1	27.9	43.1 - 112.9	89.4	112.2
SECCHI (METERS)	0.5 - 0.6	0.6	0.6	0.9 - 1.2	1.1	1.1	0.3 - 0.5	0.4	0.5

B. Biological characteristics:

1. Phytoplankton -

Sampling Date	Dominant Genera	Algal Units per ml
04/26/74	1. Stephanodiscus sp.	13,131
	2. Dactylococcopsis sp.	6,194
	3. Chroomonas sp.	3,592
	4. Ankistrodesmus sp.	1,982
	5. Synedra sp.	1,734
	Other genera	4,460
	Total	31,093
07/10/74	1. Aphanizomenon sp.	17,930
	2. Microcystis sp.	448
	3. Cryptomonas sp.	299
	4. Crucigenia sp.	299
	5. Melosira sp.	150
	Other genera	223
	Total	19,349
09/18/74	1. Oscillatoria sp.	9,303
	2. Aphanizomenon sp.	7,612
	3. Stephanodiscus sp.	4,229
	4. Chroomonas sp.	3,637
	5. Dactylococcopsis sp.	2,876
	Other genera	12,432
	Total	40,089

2. Chlorophyll a -

Sampling Date	Station Number	Chlorophyll a (µg/l)
04/26/74	1	14.1
	2	24.6
	3	50.7
07/10/74	1	19.8
	2	224.6
	3	36.1
09/18/74	1	43.1
	2	112.2
	3	112.9

C. Limiting Nutrient Study:

1. Autoclaved, filtered, and nutrient spiked -

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum yield (mg/l-dry wt.)
Control	0.160	0.278	12.2
0.050 P	0.210	0.278	13.2
0.050 P + 1.0 N	0.210	1.278	29.1
1.0 N	0.160	1.278	30.0

2. Discussion -

The control yield of the assay alga, Selenastrum capricornutum, indicates that the potential primary productivity of Sand Lake was high at the time the sample was collected (09/18/74). Also, the lack of significant yield increase with the addition of phosphorus alone until nitrogen was also added indicates that the lake was nitrogen limited at that time. Note that the addition of only nitrogen resulted in a yield much greater than that of the control.

The lake data indicate nitrogen limitation as well; i.e., the mean inorganic nitrogen/orthophosphorus ratios were 4/1 or less at all sampling times, and nitrogen limitation would be expected.

IV. NUTRIENT LOADINGS
(See Appendix E for data)

For the determination of nutrient loadings, the South Dakota National Guard collected monthly near-surface grab samples from each of the tributary sites indicated on the map (page v), except for the high runoff month of October when two samples were collected. Sampling was begun in October, 1974, and was completed in September, 1975.

Through an interagency agreement, stream flow estimates for the year of sampling and a "normalized" or average year were provided by the South Dakota District Office of the U.S. Geological Survey for the tributary sites nearest the lake.

In this report, nutrient loads for the James River were determined by using a modification of a U.S. Geological Survey computer program for calculating stream loadings*. Nutrient loads shown are those measured minus point-source loads, if any.

Nutrient loads for Dry Run and the unsampled "minor tributaries and immediate drainage" ("ZZ" of U.S.G.S.) were estimated using the nutrient loads at station A-2, in kg/km^2/year, and multiplying by the Dry Run and ZZ areas in km^2.

The operators of the LaMoure and Oakes, North Dakota, wastewater treatment ponds did not participate; nutrient loads from these sources were estimated at 1.134 kg P and 3.401 kg N/capita/year, and flows were estimated at 0.3785 m^3/capita/day.

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* See Working Paper No. 175.

Estimates of the nutrient contributions of migratory ducks and geese are based on waterfowl inventory data and refuge information provided by Refuge Manager William Blair (1976).

In 1974-75, goose-use days totaled 6,500,000; and duck-use days totaled 15,000,000.

In calculating the nutrient loads, the following assumptions were made:

1. Four percent of the geese were lesser Canadas, one percent were greater Canadas, 95 percent were snow and blue geese, and essentially all of the ducks were mallards.

2. The geese spent one-half of the time away from the refuge waters; i.e., effective goose-use days = 3,250,000.

3. Mallard ducks spent one-third of the time away from the refuge waters; i.e., effective mallard-use days = 10,000,000.

4. Other ducks, coots, etc., spent practically all of the time on the refuge waters and thus essentially recycled nutrients from the lake back to the lake.

5. The physiology of waste excretion is similar among waterfowl, and the amount of feces produced is approximately proportional to body weight (Hutchinson, 1950).

6. The mean weight of common Canada geese is 3.870 kg, the mean weight of lesser Canada geese is 2.183 kg, the mean weight of snow-blue geese is 2.289 kg, and the mean weight of mallard ducks is 1.148 kg (Kortright, 1943).

7. The estimated mean weight of greater Canada geese is 5.896 kg (Bair, op. cit.).

8. Common Canada geese contribute 0.439 g total phosphorus and 1.435 g total nitrogen per goose-use day (Manny et al., 1975).

A. Waste Sources:

1. Known municipal* -

Name	Pop. Served	Treatment	Mean Flow (m^3/d)	Receiving Water
LaMoure	900	stab. pond	340.6	James River
Oakes	1,800	stab. pond	681.3	James River

*Anonymous, 1971.

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	kg P/ yr	% of total
a. Tributaries (non-point load) -		
James River	15,725	71.8
Dry Run	260	1.2
b. Minor tributaries & immediate drainage (non-point load) -	665	3.0
c. Known municipal STP's -		
LaMoure	1,020	4.7
Oakes	2,040	9.3
d. Septic tanks - Unknown	?	-
e. Known industrial - None	-	-
f. Waterfowl -		
Ducks	1,300	5.9
Geese	850	3.9
g. Direct precipitation* -	55	0.2
Total	21,915	100.0

2. Outputs -

Lake outlet - James River 17,010

3. Net annual P accumulation - 4,905 kg.

* See Working Paper No. 175.

C. Annual Total Nitrogen Loading - Average Year:

1. Inputs -

Source	kg N/yr	% of total
a. Tributaries (non-point load) -		
James River	154,140	85.1
Dry Run	2,070	1.2
b. Minor tributaries & immediate drainage (non-point load) -	5,340	2.9
c. Known municipal STP's -		
LaMoure	3,060	1.7
Oakes	6,120	3.4
d. Septic tanks - Unknown	?	-
e. Known industrial - None	-	-
f. Waterfowl -		
Ducks	4,260	2.4
Geese	2,795	1.5
g. Direct Precipitation* -	3,345	1.8
Total	181,130	100.0

2. Outputs -

Lake outlet - James River 142,740

3. Net annual N accumulation - 38,390 kg.

* See Working Paper No. 175.

D. Mean Annual Non-point Nutrient Export by Subdrainage Area:

Tributary	kg P/km²/yr	kg N/km²/yr
James River	2	16

E. Mean Nutrient Concentrations in the James River:

	Mean Total P Conc. (mg/l)	Mean Total N Conc. (mg/l)
At station A-1 (outlet)	0.265	2.327
At station A-2 (inlet)	0.247	2.117
Difference	0.018	0.210
% difference	7	10

F. Yearly Loads:

In the following table, the existing phosphorus loadings are compared to those proposed by Vollenweider (Vollenweider and Dillon, 1974). Essentially, his "dangerous" loading is one at which the receiving water would become eutrophic or remain eutrophic; his "permissible" loading is that which would result in the receiving water remaining oligotrophic or becoming oligotrophic if morphometry permitted. A mesotrophic loading would be considered one between "dangerous" and "permissible".

Note that Vollenweider's model may not be applicable to water bodies with short hydraulic retention times.

	Total Phosphorus		Total Nitrogen	
	Total	Accumulated	Total	Accumulated
grams/m^2/yr	7.07	1.58	58.4	12.4

Vollenweider phosphorus loadings ($g/m^2/yr$) based on mean depth and mean hydraulic retention time of Sand Lake:	
"Dangerous" (eutrophic loading)	0.96
"Permissible" (oligotrophic loading)	0.48

V. LITERATURE REVIEWED

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VI. APPENDICES

APPENDIX A

LAKE RANKINGS

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500-MEAN SEC	MEAN CHLORA	15-MIN DO	MEDIAN DISS ORTHO P
4601	LAKE ALBERT	0.321	0.170	489.111	106.289	9.200	0.019
4602	ALVIN LAKE	0.067	0.970	442.833	4.700	9.400	0.017
4603	ANGOSTURA RESERVOIR	0.019	0.160	423.333	3.717	13.000	0.005
4604	BRANT LAKE	0.194	0.130	432.833	34.150	11.800	0.113
4605	LAKE BYRON	0.443	0.370	488.333	149.350	9.000	0.146
4606	CLEAR LAKE	0.027	0.075	430.167	11.983	8.800	0.009
4607	CLEAR LAKE	1.400	0.270	495.333	691.000	7.000	0.468
4608	COCHRANE LAKE	0.037	0.150	446.000	15.683	15.000	0.008
4609	COTTONWOOD LAKE	0.685	0.265	490.333	112.017	8.600	0.417
4610	DEERFIELD RESERVOIR	0.033	0.080	303.333	3.650	15.000	0.022
4611	ENEMY SWIM LAKE	0.037	0.085	442.600	14.200	8.200	0.013
4612	LAKE HERMAN	0.340	0.155	485.000	58.733	8.600	0.174
4613	ST JOHN LAKE	0.349	0.080	489.400	120.880	9.800	0.025
4614	LAKE KAMPESKA	0.220	0.105	468.889	20.567	8.200	0.128
4615	MADISON LAKE	0.259	0.090	445.555	22.578	14.000	0.107
4616	LAKE MITCHELL	0.099	0.085	465.833	14.883	13.800	0.015
4617	LAKE NORDEN	0.256	0.165	488.667	46.800	10.000	0.050
4618	OAKWOOD LAKE EAST	0.146	0.175	487.000	113.600	10.000	0.009
4619	OAKWOOD LAKE WEST	0.181	0.135	485.833	159.667	9.600	0.021
4620	PACTOLA RESERVOIR	0.011	0.070	248.444	1.478	11.000	0.006
4621	PICKEREL LAKE	0.049	0.095	439.833	15.833	9.600	0.009
4622	LAKE POINSETT	0.115	0.315	468.444	40.211	10.000	0.023
4623	LAKE RED IRON SOUTH	0.042	0.110	430.333	6.883	7.600	0.010
4624	RICHMOND LAKE	0.187	0.150	410.000	18.467	10.000	0.144
4625	ROY LAKE	0.034	0.070	431.000	13.333	11.000	0.010
4626	SAND LAKE	0.489	0.110	471.800	65.790	12.800	0.288
4627	SHERIDAN LAKE	0.053	0.105	394.000	15.433	15.000	0.016
[illegible]9	STOCKADE LAKE	0.233	0.150	432.000	25.400	15.000	0.109

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500-MEAN SEC	MEAN CHLORA	15-MIN DO	MEDIAN DISS ORTHO P
4629	LAKE VERMILLION	0.211	0.100	472.833	100.800	9.200	0.092
4630	WALL LAKE	0.194	0.160	441.667	55.267	7.400	0.076
4631	WAUBAY LAKE NORTH	0.098	0.145	469.555	127.033	11.400	0.023

PERCENT OF LAKES WITH HIGHER VALUES (NUMBER OF LAKES WITH HIGHER VALUES)

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500-MEAN SEC	MEAN CHLORA	1S-MIN DO	MEDIAN DISS ORTHO P	INDEX NO
4601	LAKE ALBERT	20 (6)	20 (6)	10 (3)	23 (7)	68 (20)	60 (18)	201
4602	ALVIN LAKE	67 (20)	0 (0)	57 (17)	90 (27)	63 (19)	63 (19)	340
4603	ANGOSTURA RESERVOIR	97 (29)	30 (9)	87 (26)	93 (28)	20 (6)	100 (30)	427
4604	BRANT LAKE	40 (12)	53 (16)	70 (21)	47 (14)	27 (8)	23 (7)	260
4605	LAKE BYRON	10 (3)	3 (1)	17 (5)	7 (2)	73 (22)	13 (4)	123
4606	CLEAR LAKE	93 (28)	93 (28)	83 (25)	83 (25)	77 (23)	90 (27)	519
4607	CLEAR LAKE	0 (0)	10 (3)	0 (0)	0 (0)	100 (30)	0 (0)	110
4608	COCHRANE LAKE	83 (25)	40 (11)	50 (15)	67 (20)	5 (0)	93 (28)	338
4609	COTTONWOOD LAKE	3 (1)	13 (4)	3 (1)	20 (6)	82 (24)	3 (1)	124
4610	DEERFIELD RESERVOIR	90 (27)	88 (26)	97 (29)	97 (29)	5 (0)	53 (16)	430
4611	ENEMY SWIM LAKE	80 (24)	82 (24)	60 (18)	77 (23)	88 (26)	73 (22)	460
4612	LAKE HERMAN	17 (5)	33 (10)	27 (8)	33 (10)	82 (24)	10 (3)	202
4613	ST JOHN LAKE	13 (4)	88 (26)	7 (2)	13 (4)	53 (16)	43 (13)	217
4614	LAKE KAMPESKA	33 (10)	65 (19)	40 (12)	57 (17)	88 (26)	20 (6)	303
4615	MADISON LAKE	27 (8)	77 (23)	53 (16)	53 (16)	13 (4)	30 (9)	253
4616	LAKE MITCHELL	60 (18)	82 (24)	47 (14)	73 (22)	17 (5)	70 (21)	349
4617	LAKE NORDEN	23 (7)	23 (7)	13 (4)	40 (12)	45 (12)	40 (12)	184
4618	OAKWOOD LAKE EAST	53 (16)	17 (5)	20 (6)	17 (5)	45 (12)	85 (25)	237
4619	OAKWOOD LAKE WEST	50 (15)	50 (15)	23 (7)	3 (1)	58 (17)	57 (17)	241
4620	PACTOLA RESERVOIR	100 (30)	98 (29)	100 (30)	100 (30)	35 (10)	97 (29)	530
4621	PICKEREL LAKE	73 (22)	73 (22)	67 (20)	63 (19)	58 (17)	85 (25)	419
4622	LAKE POINSETT	57 (17)	7 (2)	43 (13)	43 (13)	45 (12)	47 (14)	242
4623	LAKE RED IRON SOUTH	77 (23)	58 (17)	80 (24)	87 (26)	93 (28)	78 (23)	473
4624	RICHMOND LAKE	47 (14)	40 (11)	90 (27)	60 (18)	45 (12)	17 (5)	299
4625	ROY LAKE	87 (26)	98 (29)	77 (23)	80 (24)	35 (10)	78 (23)	455
4626	SAND LAKE	7 (2)	58 (17)	33 (10)	30 (9)	23 (7)	7 (2)	158
4627	SHERIDAN LAKE	70 (21)	65 (19)	93 (28)	70 (21)	5 (0)	67 (20)	370
[illegible]8	STOCKADE LAKE	30 (9)	40 (11)	73 (22)	50 (15)	5 (0)	27 (8)	225

PERCENT OF LAKES WITH HIGHER VALUES (NUMBER OF LAKES WITH HIGHER VALUES)

LAKE CODE	LAKE NAME	MEDIAN TOTAL P	MEDIAN INORG N	500-MEAN SEC	MEAN CHLORA	15-MIN DO	MEDIAN DISS ORTHO P	INDEX NO
4629	LAKE VERMILLION	37 (11)	70 (21)	30 (9)	27 (8)	68 (20)	33 (10)	265
4630	HALL LAKE	43 (13)	27 (8)	63 (19)	37 (11)	97 (29)	37 (11)	304
4631	HANNAY LAKE NORTH	63 (19)	47 (14)	37 (11)	10 (3)	30 (9)	50 (15)	237

LAKES RANKED BY INDEX NOS.

RANK	LAKE CODE	LAKE NAME	INDEX NO
29	4609	COTTONWOOD LAKE	124
30	4605	LAKE BYRON	123
31	4607	CLEAR LAKE	110

AKES RANKED BY INDEX NOS.

RANK	LAKE CODE	LAKE NAME	INDEX NO
1	4620	PACTOLA RESERVOIR	530
2	4606	CLEAR LAKE	519
3	4623	LAKE RED IRON SOUTH	473
4	4611	ENEMY SWIM LAKE	460
5	4625	ROY LAKE	455
6	4610	DEERFIELD RESERVOIR	430
7	4603	ANGOSTURA RESERVOIR	427
8	4621	PICKEREL LAKE	419
9	4627	SHERIDAN LAKE	370
10	4616	LAKE MITCHELL	349
11	4602	ALVIN LAKE	340
12	4608	COCHRANE LAKE	338
13	4630	WALL LAKE	304
14	4614	LAKE KAMPESKA	303
15	4624	RICHMOND LAKE	299
16	4629	LAKE VERMILLION	265
17	4604	BRANT LAKE	260
18	4615	MADISON LAKE	253
19	4622	LAKE POINSETT	242
20	4619	OAKWOOD LAKE WEST	241
21	4631	WAUBAY LAKE NORTH	237
22	4618	OAKWOOD LAKE EAST	237
23	4628	STOCKADE LAKE	225
24	4613	ST JOHN LAKE	217
25	4612	LAKE HERMAN	202
26	4601	LAKE ALBERT	201
27	4617	LAKE NORDEN	184
28	4626	SAND LAKE	158

APPENDIX B

CONVERSION FACTORS

CONVERSION FACTORS

Hectares x 2.471 = acres

Kilometers x 0.6214 = miles

Meters x 3.281 = feet

Cubic meters x 8.107×10^{-4} = acre/feet

Square kilometers x 0.3861 = square miles

Cubic meters/sec x 35.315 = cubic feet/sec

Centimeters x 0.3937 = inches

Kilograms x 2.205 = pounds

Kilograms/square kilometer x 5.711 = lbs/square mile

APPENDIX C

TRIBUTARY FLOW DATA

TRIBUTARY FLOW INFORMATION FOR SOUTH DAKOTA 05/03/76

LAKE CODE 4626 SAND

TOTAL DRAINAGE AREA OF LAKE(SQ KM) 10308.2

TRIBUTARY	SUB-DRAINAGE AREA(SQ KM)	NORMALIZED FLOWS(CMS) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
4626A1	10308.2	0.17	0.11	0.34	9.17	7.19	4.16	3.54	1.81	0.62	0.48	0.57	0.42	2.39
4626A2	9842.0	0.34	0.34	3.60	9.20	3.34	4.33	3.06	1.25	0.91	0.88	0.57	0.42	2.35
4626B1	129.5	0.0	0.0	0.028	0.028	0.028	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.007
4626ZZ	336.7	0.0	0.0	0.028	0.028	0.028	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.007

SUMMARY

TOTAL DRAINAGE AREA OF LAKE = 10308.2
SUM OF SUB-DRAINAGE AREAS = 10308.2

TOTAL FLOW IN = 28.40
TOTAL FLOW OUT = 28.60

MEAN MONTHLY FLOWS AND DAILY FLOWS(CMS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
4626A1	10	74	0.142	12	0.0	30	0.057		
	11	74	0.170	8	0.113				
	12	74	0.170	12	0.170				
	1	75	0.170	26	0.170				
	2	75	0.113	28	0.085				
	3	75	0.057	13	0.0				
	4	75	1.416	20	1.784				
	5	75	18.264	16	20.841				
	6	75	12.714						
	7	75	33.216	1	21.464	26	30.865		
	8	75	18.859	23	16.141				
	9	75	10.817	27	9.373				
4626A2	10	74	1.189	12	1.841	30	0.566		
	11	74	0.481	8	0.623				
	12	74	0.283	12	0.340				
	1	75	0.272	26	0.255				
	2	75	0.283	28	0.283				
	3	75	0.595	13	0.283				
	4	75	18.066	20	28.317				
	5	75	18.094	16	15.857				
	6	75	13.762						
	7	75	36.359	1	127.426	26	7.929		
	8	75	7.957	23	8.212				
	9	75	8.212	27	7.929				

TRIBUTARY FLOW INFORMATION FOR SOUTH DAKOTA 05/03/76

LAKE CODE 4676 SAND

MEAN MONTHLY FLOWS AND DAILY FLOWS(CMS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
462681	10	74	0.0	12	0.0	30	0.0		
	11	74	0.0	8	0.0				
	12	74	0.0	12	0.0				
	1	75	0.0	26	0.0				
	2	75	0.0	28	0.0				
	3	75	0.0	13	0.0				
	4	75	0.001	20	0.006				
	5	75	0.0	16	0.0				
	6	75	0.0						
	7	75	0.0	1	0.0	26	0.0		
	8	75	0.0	23	0.0				
	9	75	0.0	27	0.0				
4626ZZ	10	74	0.0						
	11	74	0.0						
	12	74	0.0						
	1	75	0.0						
	2	75	0.0						
	3	75	0.0						
	4	75	0.0						
	5	75	0.001						
	6	75	0.0						
	7	75	0.0						
	8	75	0.0						
	9	75	0.0						

APPENDIX D

PHYSICAL and CHEMICAL DATA

STORET RETRIEVAL DATE 76/05/03

462601
45 40 03.0 098 18 20.0 3
SAND LAKE
46013 SOUTH DAKOTA

090691

11EPALES 2111202
0002 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00610 NH3-N TOTAL MG/L	00625 TOT KJEL N MG/L	00630 NO2&NO3 N-TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P
74/04/26	11 00	0000	16.0	9.2	24	870	8.25	366	0.050	1.700	0.040	0.034
74/07/10	14 25	0000	25.1	2.2	48	980	8.30	296	0.100	2.000	0.060	0.433
	14 26	0000	25.1	2.2	48	980	8.30	314	0.120	1.700	0.070	0.445
74/09/18	10 45	0000	16.4	8.2	18	849	7.81	630	0.040	2.700	0.020K	0.288

DATE FROM TO	TIME OF DAY	DEPTH FEET	00665 PHOS-TOT MG/L P	32217 CHLRPHYL A UG/L	00031 INCDT LT REMNING PERCENT
74/04/26	11 00	0000	0.142	14.1	
74/07/10	14 25	0000	0.544	19.8	
	14 26	0000	0.576	19.8	
74/09/18	10 45	0000	0.640	43.1	
	10 45	0003			1.0

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 76/05/03

462602
45 43 20.0 098 17 22.0 3
SAND LAKE
46013 SOUTH DAKOTA
090691

11EPALES 2111202
0004 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00610 NH3-N TOTAL MG/L	00625 TOT KJEL N MG/L	00630 NO2&NO3 N-TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P
74/04/26	11 15	0000	13.0	9.4	24	817	8.50	364	0.050	1.800	0.060	0.018
74/07/10	14 05	0000	27.3	15.8	36	957	9.60	280	0.100	3.600	0.070	0.310
	14 05	0002	27.3	15.8		957	9.60	300	0.080	4.400	0.050	0.307
74/09/18	10 35	0000	15.8	10.2	18	766	8.53	490	0.060	3.200	0.030	0.109

DATE FROM TO	TIME OF DAY	DEPTH FEET	00665 PHOS-TOT MG/L P	32217 CHLRPHYL A UG/L	00031 INCDT LT REMNING PERCENT
74/04/26	11 15	0000	0.157	24.6	
74/07/10	14 05	0000	0.505	224.6	
	14 05	0002	0.564		
74/09/18	10 35	0000	0.306	112.2	
	10 35	0002			1.0

STORET RETRIEVAL DATE 76/05/03

462603
45 46 40.0 098 14 44.0 3
SAND LAKE
46013 SOUTH DAKOTA

090691

11EPALES 2111202
0002 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00610 NH3-N TOTAL MG/L	00625 TOT KJEL N MG/L	00630 NO2&NO3 N-TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P
74/04/26	11 30	0000	16.0	10.0	18	496	8.55	162	0.050	1.700	0.060	0.031
74/07/10	14 50	0000	27.6	7.2	36	817	8.90	298	0.120	2.200	0.090	0.414
74/09/18	10 20	0000	16.8	8.9	12	698	8.53	445	0.050	3.300	0.020	0.056

DATE FROM TO	TIME OF DAY	DEPTH FEET	00665 PHOS-TOT MG/L P	32217 CHLRPHYL A UG/L	00031 INCDT LT REMNING PERCENT
74/04/26	11 30	0000	0.311	50.7	
74/07/10	14 50	0000	0.489	36.1	
74/09/18	10 20	0000	0.304	112.9	
	10 20	0002			1.0

APPENDIX E

TRIBUTARY DATA

STORET RETRIEVAL DATE 76/05/04

462641
45 40 05.0 098 18 35.0 4
JAMES RIVER
46 7.5 COLUMBIA NE
U/SAND RESERVOIR 090691
SEC RD BRDG 1 MI BELOW COLUMBIA ROAD DAM
11EPALES 2111204
0000 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
74/10/12	11 08		0.008	3.600	0.040	0.090	0.410
74/10/30	14 45		0.008	4.100	0.055	0.120	0.420
74/11/08	16 45		0.008	2.300	0.055	0.125	0.280
75/02/28	16 00		0.070	3.200	0.407	0.240	0.360
75/04/20	16 00		0.060	1.900	0.290	0.050	0.180
75/05/16	18 35		0.005	1.450	0.030	0.040	0.100
75/07/01	20 10		0.010	1.300	0.055	0.185	0.200
75/07/26	20 00		0.015	1.200	0.025	0.230	0.310
75/08/23	19 00		0.020	2.200	0.035	0.065	0.220
75/09/27	20 00		0.020	1.800	0.015	0.020	0.170

STORET RETRIEVAL DATE 76/05/04

4626A2
45 56 10.0 098 10 30.0 4
JAMES RIVER
46 7.5 HECLA
T/SAND RESERVOIR 090691
SEC RD BRDG 5.4 MI NW OF HECLA
11EPALES 2111204
0000 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
74/10/12	12 25		0.024	2.400	0.030	0.030	0.210
74/10/30	12 15		0.024	2.000	0.060	0.060	0.400
74/11/08	16 07		0.184	2.900	0.120	0.090	0.170
75/04/20	15 05		0.350	1.250	0.100	0.170	0.280
75/05/16	17 50		0.005	2.100	0.035	0.030	0.170
75/07/01	20 00		0.150	1.600	0.308	0.175	0.340
75/07/26	17 30		0.020	2.100	0.020	0.090	0.290
75/08/23	17 30		0.155	1.450	0.015	0.040	0.170
75/09/27	19 30		0.140	2.200	0.015	0.015	0.190

STORET RETRIEVAL DATE 76/05/04

462681
45 49 15.0 098 15 20.0 4
DRY RUN
46 7.5 SAVO SE
T/SAND RESERVOIR 090691
SEC RD BRDG 7.5 MI NW OF HOUGHTON
11EPALES 2111204
0000 FEET DEPTH CLASS 00

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
75/04/20	14 30		0.250	3.000	0.400	0.750	0.850
75/05/16	17 20		0.005	3.160	0.055	0.360	0.520
75/07/01	18 15		0.025	3.800	0.360	0.430	0.580
75/07/26	16 30		0.010	4.600	0.080	2.500	3.000
75/08/23	17 00		0.015	4.700	0.070	1.100	1.700
75/09/27	18 15		0.015	7.700	0.045	0.525	1.400